SELECTIVELY DEFORMABLE STRUCTURES FOR DESIGN OF ADAPTIVE WING SMART ELEMENTS

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Abstract

The results of multidisciplinary research activities focusing on the "use of aeroelasticity" concept are presented. Development and evaluation of the potential of morphing airframe technologies based on Selectively Deformable Structures (SDS) is observed.

The principal scheme of large-scale SADE project demonstrator for the wind tunnel of TsAGI T-101 is shown. The principal tasks for demonstrator are wind tunnel tests, ground vibration and stiffness measurements to show main advantages of adaptive smart elements of the wing.

1 Introduction

This paper presents results of research activities based on finite element models by using MSC.Patran, MSC.Nastran, MSC.Marc and focusing on the "use of aeroelasticity" concept. Development and evaluation of the potential of morphing airframe technologies based on SDS - Selectively Deformable Structures as one of the promising concept for smart structures is investigated. It is important to be aware of the known fact in advanced composite design: stiffness, elasticity and strength are not scalar, but tensored properties. Therefore, it is possible to combine required strength and stiffness with selective deformability as perspective opportunity to design of adaptive wings.

The development of selectively deformable structures and the smart integration of optimized actuators is the root challenge of morphing. The main principle of SDS was to create a material (structure), which has a minimal Poisson's effect: a force applied to this material should result in a deflection along the direction of the acting load, with only a minimal deformation in the transverse direction. This effect is achieved through designing the internal structure as a special cellular network. The individual cell can be described essentially as moment-resisting frame. Deformations of this type of preferably composite structure may be resolved into two components: traction-contraction, and flexural deflections.

2 SADE Project of the 7th European Framework Program.

Central aerohydrodynamic institute, TsAGI, Russia takes active part in the international SADE Project of the 7th European Framework Program. Abbreviation SADE (**S**m**A**rt High Lift **DE**vices for Next Generation Wing) means: smart elements of mechanization of a wing of following generation. The aim of the project is to increase aerodynamic quality (lift to drag ratio) and fuel efficiency of the future transport airplanes, while reducing noise and emissions in all flight regimes (take-off and landing cases in the first instance). One promising way to solve these problems is the application of controls of specific (adaptive) designs, ensuring their smooth, slotless and zero-gap deflection. Thus the possibility of rational regulation airfoil shape is achieved.

In project SADE some variants of a design of wing's adaptive leading and trailing edges are considered. The task is based on an integrated computational and experimental study of the options proposed by a number of partners to choose the most promising in aerodynamic and weight relations. The project will last four years working together 13 partners of the leading scientific and engineering aviation centers of Europe and should be completed in 2012 tests in the large subsonic wind tunnel T-101 TsAGI large area model wings with adaptive elements of mechanization. TsAGI responsible for a package of work (design and fabrication) of a wing box, model end plates and model's wind tunnel supporting elements.

Further TsAGI carries out also connection with a wing box of adaptive leading edge elements and single-slot flap, designed and manufactured by our European partners. TsAGI is also responsible for model strain-stress analysis, stiffness and ground vibration tests.

Last stage of the work provided by TsAGI with European partners participation are wind tunnel tests, pressure distribution and strain-gage measurements, optical videogrammetric measurements, safe wind tunnel tests taking into account flutter and other aeroelasticity problem.

3 Two Variants of Smart Leading Edge based on Selectively Deformable Structures

The starting point of the project was TsAGI research in the field of adaptive wing, and above all - the invention TsAGI, connected with actively morphing materials - the so-called selectively deformable structures - SDS. The basis for these structures - the unit cell (Fig. 1), which has a minimum stiffness in tension and compression in one direction at a given bending stiffness, torsional and shear stiffness, tension-compression in all other directions.

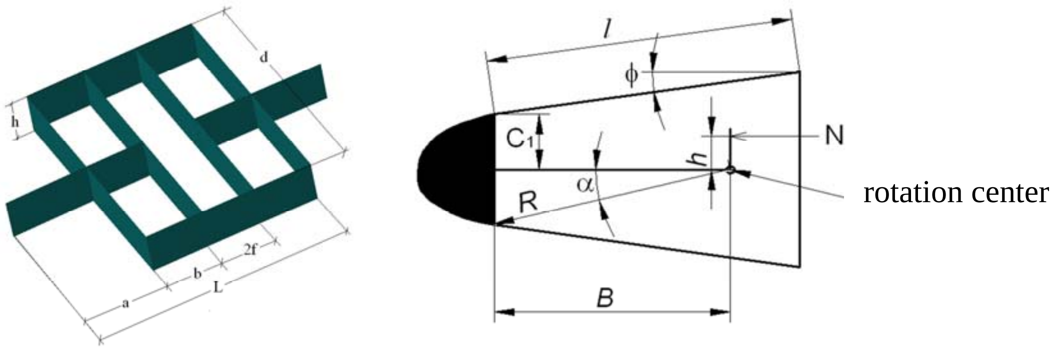

Fig. 1. The unit cell of SDS-structure; the scheme of the leading edge with smart "covering", rigid forehead of the airfoil and drive

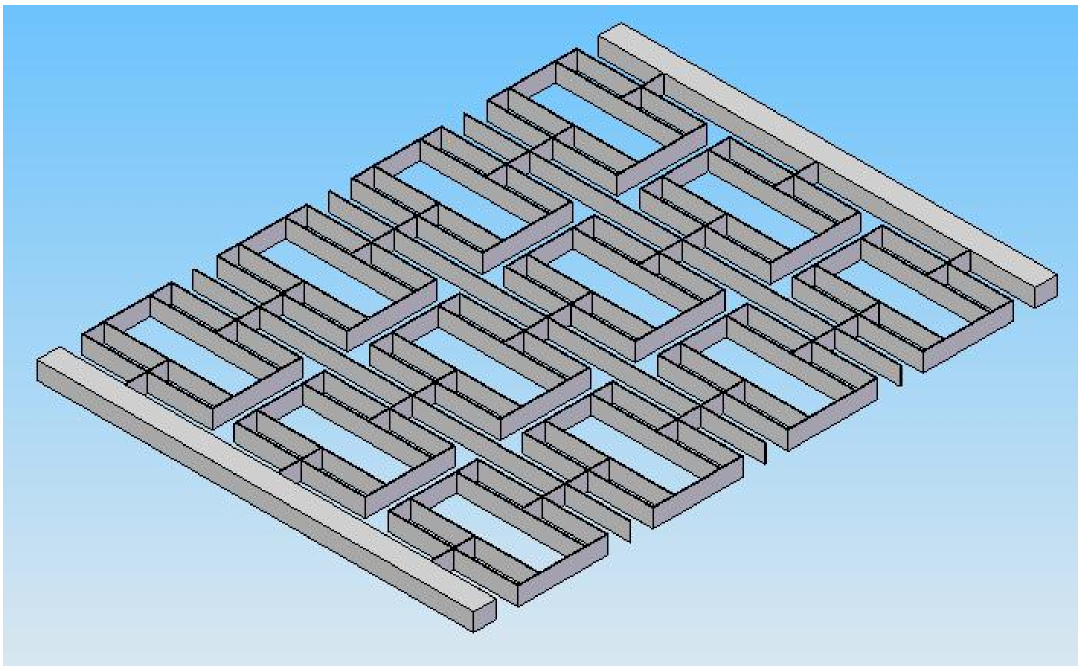

Fig. 2. Connection of elementary cells distributed in the chord and the wing span directions

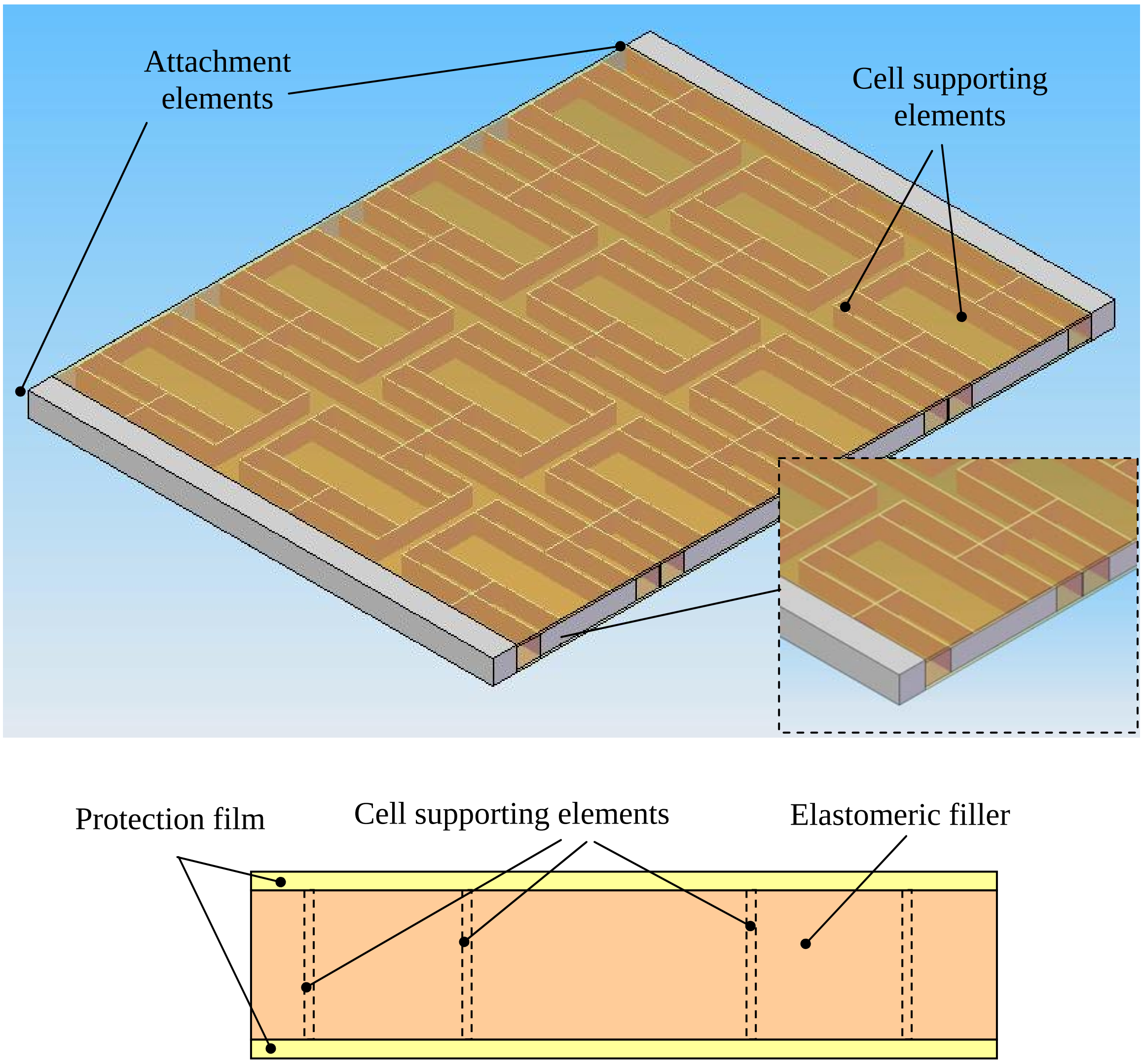

Fig. 3. Chain of elementary cell with elastomeric filler and film

This property of the SDS-structure provided by the original structure of the unit cell, the rational choice of its parameters, the material (in particular, composite) and manufacturing (in particular, a promising technology - weaving with looms, computer-controlled cars). Certain connections of such cells distributed in some chains of the chord profiles and the wing span (Fig. 2, 3) allows to create a flexible "covering", capable to accept the required airfoil shape by means of some drives and keep this form under the action of aerodynamic and mass-inertial forces.

We consider two variants of similar "covering" (Fig. 2-7). The first variant (relatively thick "covering") provides for the filling of cells with elastomeric filler, perceiving and transferring to a frame of SDS-structure aerodynamic and other loads (Fig. 4, 5). On the basis of such designs elements of wing's mechanization, providing not only slotless-structure and a smooth deviation of controls with change of its curvature, but also elements changing (increasing) of its plan area can be created.

The second variant (Fig. 6, 7) is connected with use of the flexible skin supported in a certain way by SDS-frame structure.

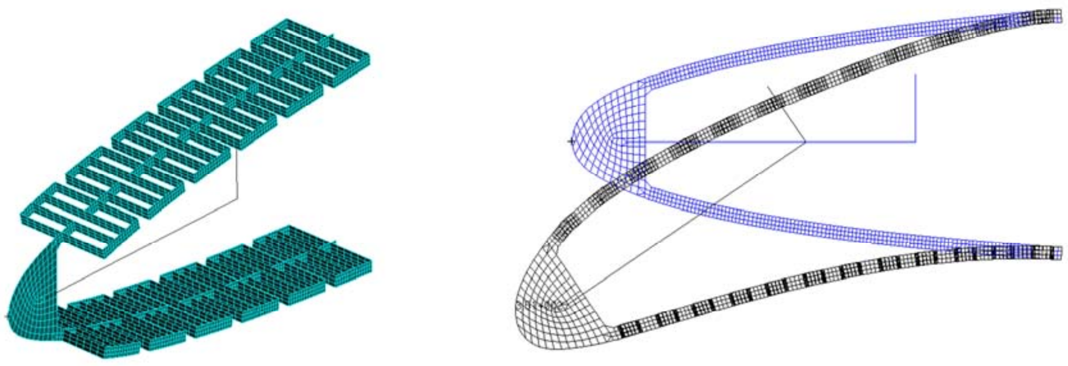

Fig. 4. The first variant of the adaptive leading edge with smart "covering" (SDS-structure and elastomeric filler)

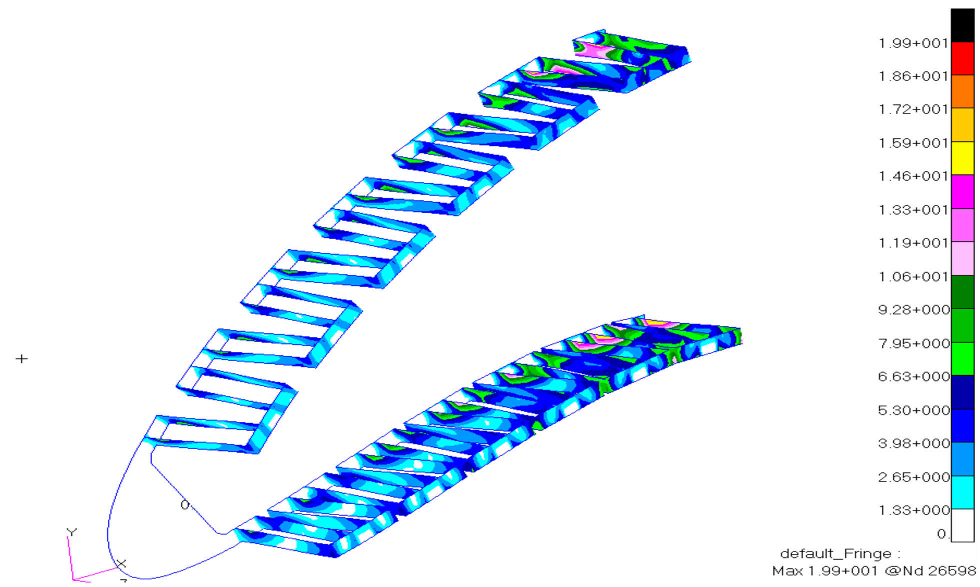

Fig. 5. Typical stress-distribution of one chordwise row of SDS-structure

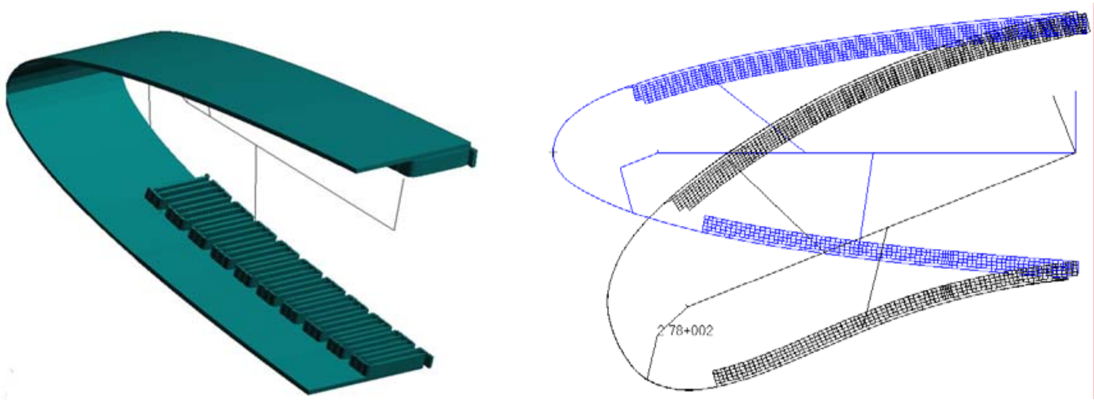

Fig. 6. The second variant of the adaptive leading edge with smart "covering"
(SDS-structure as supporting element of flexible skin), deflected by the rigid lever and hinged rods

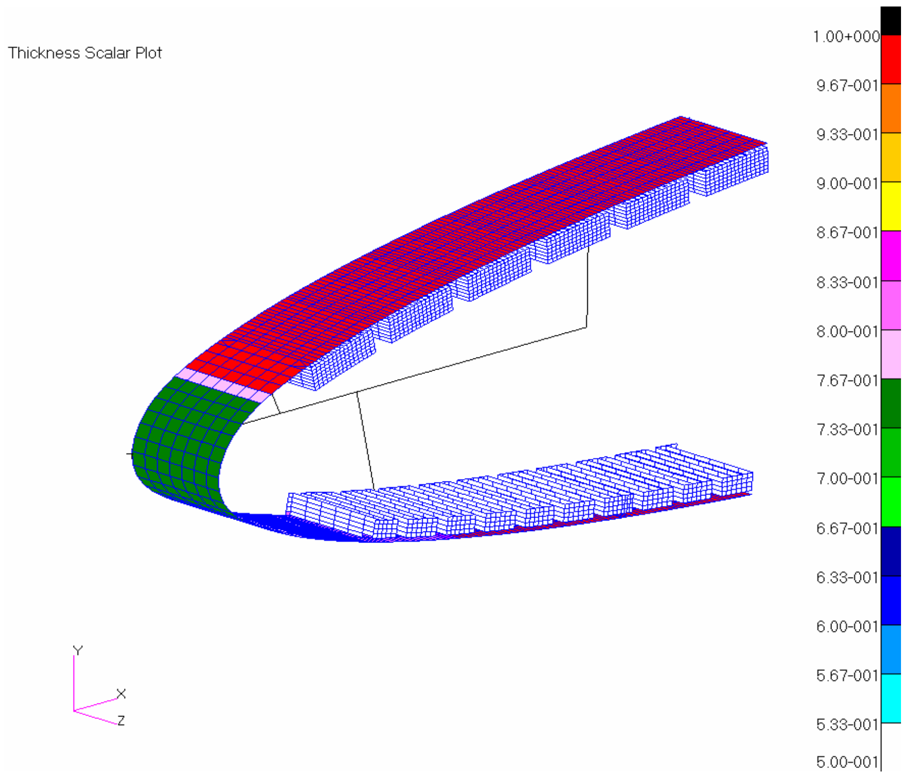

Fig. 7. Typical stress-distribution of elastic skin, supported by SDS-structure and hinged rods of the rigid lever

The first variant is rather easier on a design, is more flexible in realization of a complex airfoil of a wing on its scope, but has small local imperfections of a surface because of small deformations of elastomeric filler in the areas between the supporting elements of the SDS-structure.

In the second variant more traditional materials and technologies are used, but the variant with a flexible skin is possible only for cylindrical or conical surfaces.

4 Relations for SDS Parameters Determination

Analysis of SDS properties were performed on the basis of finite element models by using MSC.Patran, MSC.Nastran, MSC.Marc. Besides these computational analysis some simplified estimations were obtained for SDS parameters in earlier stages of study.

If we assume for simplicity, the thickness of all elements of the cell SDS identical and equal to "t" (Fig. 1), the cell flexibility on a tension-compression will be defined as:

$$\frac{U}{P} = \frac{d^3}{16EJ}\left(\frac{1}{3} - \frac{bd}{D} - \frac{d^2}{2D}\right),$$

where U is displacement of the point of application of force P.

$EJ = \frac{Eh^3 t}{12}$ is bending stiffness of the supporting elements of the cell.

Bending stiffness of the cell is equal to:

$$\frac{\varphi}{M} = \frac{1}{EJ}\left(\frac{a}{2} + \frac{d^3}{24b^2} + \frac{L}{4}\right),$$

where φ is the angle of rotation of the section under the moment M.

In both cases the deflection of the adaptive (smart) leading edge and trailing edge (flap) is carried out by means of the rigid lever (Fig. 4). For example, in the first variant force N, required for turn of a rigid nose of a profile on the angle φ, is determined by the relation:

$$N \approx \frac{R\gamma}{h} \cdot \{K_t \cdot \cos(\beta) \cdot \left(\frac{C_1}{tg\varphi} + B\right) \cdot \sin\varphi +$$
$$+ \frac{3K_b \sin\beta}{l^3} \cdot \left[\left(\frac{C_1}{tg\varphi} + B\right) \cdot \cos\varphi - \frac{C_1}{\cos^2\varphi}\right]\}$$

On fig. 1, 4 the scheme of the first variant of smart leading edge – SLE structure of the hypothetical passenger aircraft with a SDS-structure and elastomeric filler is presented.

Rigid forehead of SLE deflects (and if necessary pushed forward) by means of the rigid lever fixed together with a drive on a wall of a wing boxes forward spar.

And on fig. 6, 7 the scheme of a variant with the flexible skin, supported by SDS-structure is shown. SLE deflected by the rigid lever and a number of hinged rods, one of which is also connected with a flexible skin area of wing's forehead.

5 Smart Trailing Edge in SADE Project based on Selectively Deformable Structures

On the basis of the similar preliminary analysis in project SADE it decided to consider in more details a variant of a flap (Smart Trailing Edge – STE) with a flexible area (near to trailing edge) with elastomeric filler (fig. 8, 9).

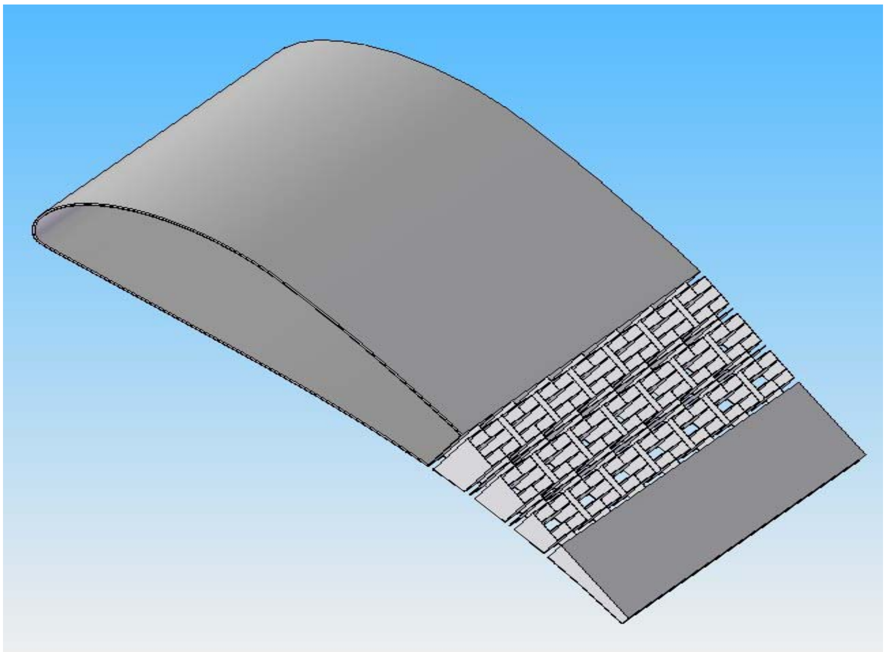

Fig. 8. Smart Trailing Edge with a flexible area (SDS-structure with elastomeric filler)

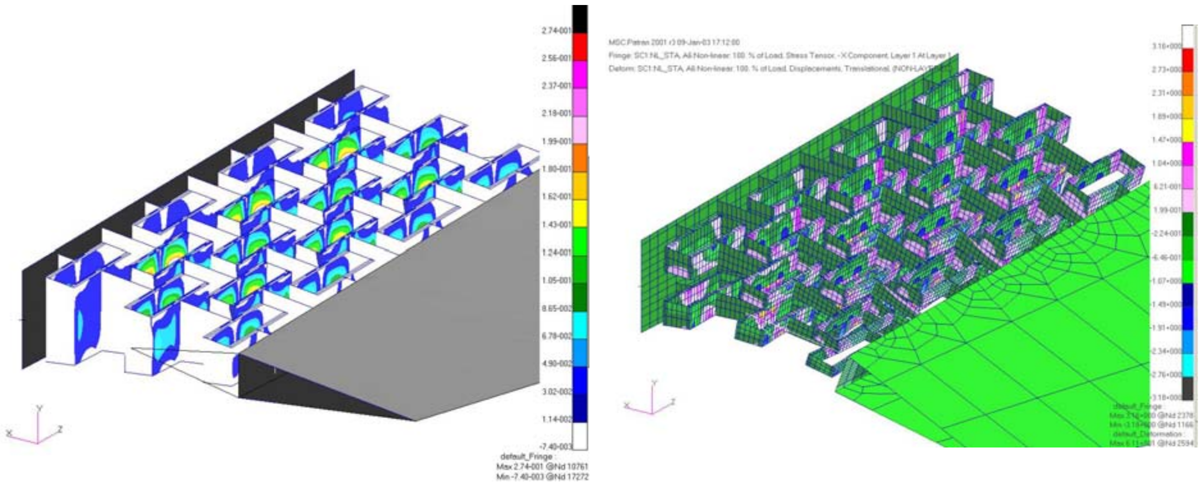

Fig. 9. Typical stress-distribution of flap flexible area (SDS-structure with elastomeric filler)

For a SLE it decided to investigate in more details a variant with the flexible skin, proposed by German experts. In this variant the flexible skin rests on a system of hinge supported rods.

SADE develops suitable "morphing" high lift devices: the slotless "smart leading edge device" is an indispensable enabler for laminar wings and offers a great benefit for reduction of acoustic emissions, the "smart single slotted flap" with active camber capability permits a further increased lift. Thanks to their ability to adapt the wing's shape, both devices also offer aerodynamic benefits for cruise flight. Morphing devices imply the integration of drive.

6 SADE Project Large-scale Demonstrator for the Wind Tunnel of TsAGI T-101

The concept of large-scale demonstrator project SADE for the wind tunnel of TsAGI T-101, which is intended to show the main advantages of adaptive elements of the wing, is shown schematically in Figure 10.

The demonstrator is a straight (unswept) wing with 5m span and 3m chord. It is installed in the test section horizontally on the upper structure of the wind tunnel and is limited by end plates. Wing box includes two metal spars and connected with them upper and lower milled metal panels (Fig. 11). The controls are fixed on the wing box (3 sections of leading edge and 1 section of single slot flap).

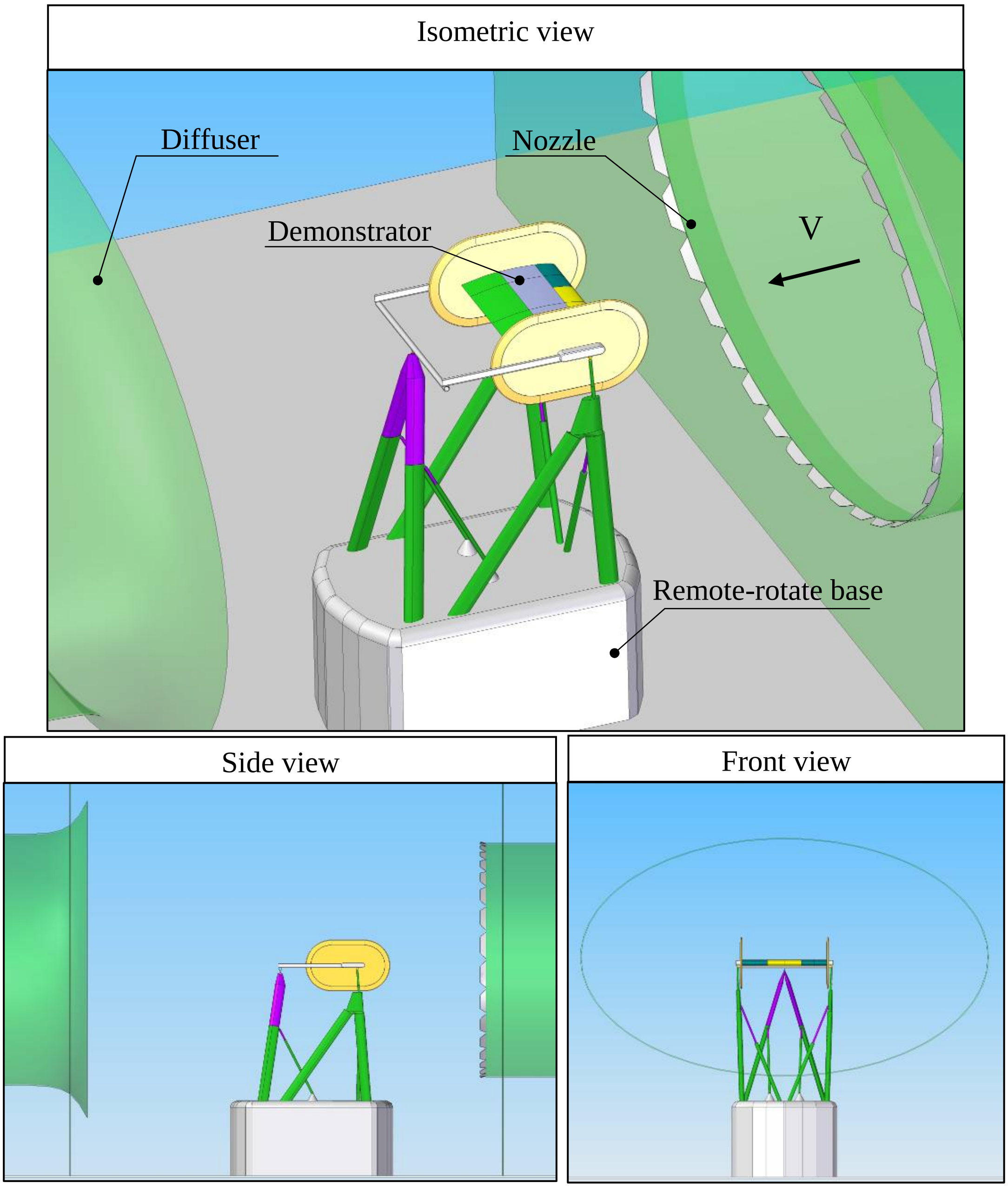

Fig. 10. Large-scale SADE project demonstrator for TsAGI T-101 aerodynamic wind tunnel

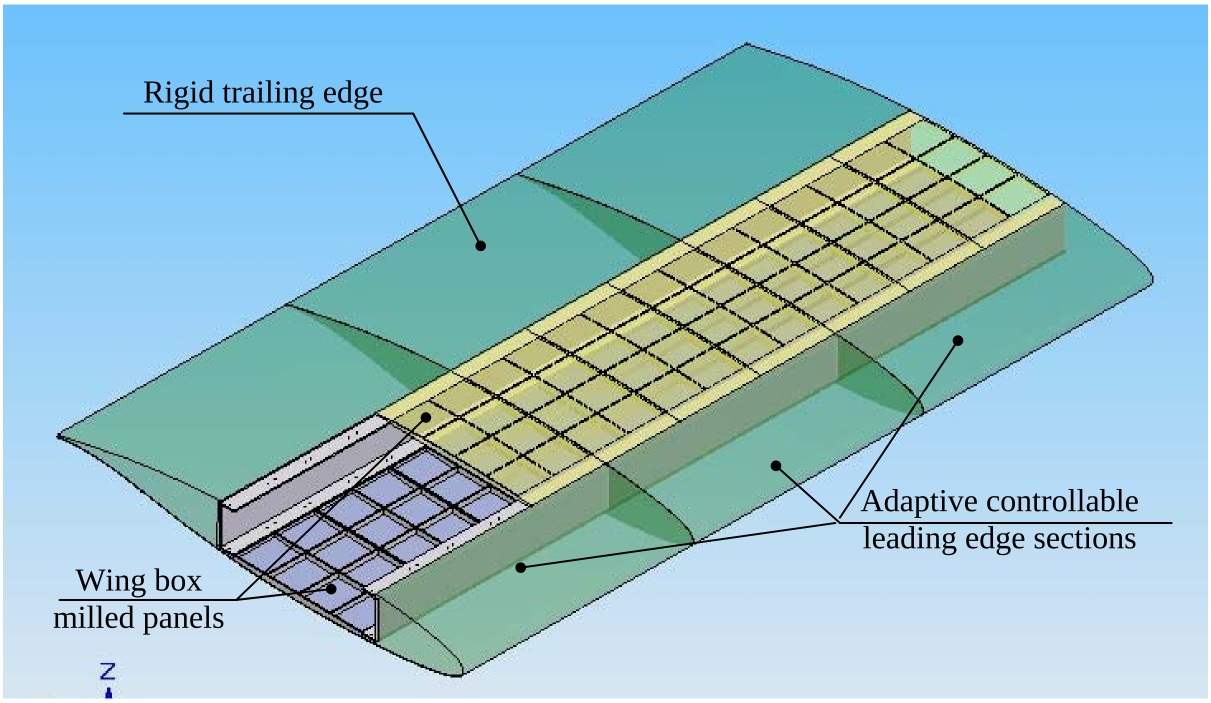

Fig. 11. Wing box with controls (3 sections of leading edge and 1 section of single slot flap).

Leading edge includes three flexible (active) smart sections, controlled by special electromechanical drive system. Demonstrator's single slot flap is fulfilled as rigid structure.

The angles of deflection of all investigated leading edge sections and trailing edge vary during the experiment. Model is drained and equipped with pressure scanner valve, straingauges, angular transducers and videogrammetric (noncontact) optical system for elastic deformation measurements.

Conclusions

SADE Project focuses on the structural challenge of realizing morphing high lift devices.

In this paper short information about results of multidisciplinary research activities focusing on the "use of aeroelasticity" concept has been presented. Development and evaluation of the potential of morphing airframe technologies based on SDS - Selectively Deformable Structures has been observed. It is believed that further evaluation and development is necessary before smart control based on SDS-structure can be used as production tool.

The principal scheme of large-scale SADE project demonstrator for the wind tunnel of TsAGI T-101 is shown. The principal task of demonstrator wind tunnel tests, ground vibration and stiffness measurements is to show main advantages of adaptive smart elements of the wing. The demonstrator that was designed can prove the feasibility of the developed by European partners concepts.

Acknowledgement

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